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WATER COOLING CONSIDERATIONS FOR THE SSC

John O'Meara
11/2/84

The purpose of this note is to specify parameters for hypothetical SSC water cooling systems, in order that the comparative advantages of these system can be studied. The various methods of heat rejection considered include:

1. Cooling Towers
2. Cooling Ponds
3. "Ground Water Recharge System"
4. Water-to-air (dry) cooling towers
5. Use of tunnel "sump" water
5. Some combination of the above

The SSC heat rejection needs occur at the east interaction area, the west interaction area and at ten major access areas. See Figure 1 for a diagram of these areas and their representative loads. Some devices are cooled directly by the pond water, others require a pond-water-to-LCW-water heat exchanger. Figure 2 contains a diagram of a typical LCW system.

The "ground water recharge" method is described in the attached reprint authored by Robert Sasman[1]. This method requires the drilling supply wells and shallower return wells. The water is used in a "once-through" heat exchanger. This method may be practical for the ten major access areas but the huge pumping water required at the east and west areas probably preclude its use in these two locations.

The ponds have been sized by Langhaar's[2] method using the average weather conditions for July at ANL's[3] weather station. This results in requiring 0.9 acres/for each MW rejected with some reserve for peak conditions. We require an average depth of five feet to provide "thermal inertia."

The cooling towers should be designed to meet the required temperature cooling range and delivery temperature under "worst" conditions, i.e. 99% of the time for the summer months. The design should be based upon "peak" conditions for flow water and heat loads. In addition the cost should assume the following requirements:

1. Prevailing industry standards apply including wind loads.
2. Windage and draft losses shall not exceed 1%.
3. Be suitable for winter use.

4. Limited degradation in performance due to winds.
5. Vendor guarantees performance for a range of operating conditions. In addition to "worst" condition point.

General Comments:

1. The cooling water temperature is likely to exceed the "max" tabulated temperature by 5 to 10 pF under worst load and weather conditions.

2. Heat rejected by Freon chillers is far greater than the horse power in. The rejection typically is 3 to 4 times as great.

3. Water quality is must be considered in determining the tendency to scale. This in turn determines blow down rate. Fermilab pond water is "good" in that typical analysis shows that is has little tendency to scale.

Attached is a copy of a calculation for scaling tendency for Fermilab pond water. On the other hand, local well water has a strong tendency to scale at increasing temperatures.

We must bear in mind that the scaling will result in a larger heat exchangers, chemical treatment of the water, frequent cleaning of heat exchangers, and/or increased power consumption.

For this note we have assumed that we can tolerate two "cycle of concentrations" in determining blow down rates shown in Table 4. This may be optimistic for well water and conservative for run-off water.

1. Cooling ponds reject heat by evaporation, conduction to the air and radiation. (Heat conduction to the earth is nil). The evaporation rate is determined by the difference in the water vapor pressure in the pond and the water vapor pressure the air. Conduction and radiation rates are determined by the difference in pond surface temperature and air temperature. Attached are plots for pond performance for January, July and September based upon ANL weather data.

   These charts show that the evaporation rates with a constant heat load vary considerably during the year. In addition the solar heat load varies with the seasons. Hence the blowdown requirements for ponds swing by about a factor of three.

2. This note assumes that the cooling towers reject heat solely by evaporation.

3. Some conversion factors:

   A) Evaporization conversion factors: 6.56 gpm/MW

   B) Water flow rate for 1pF rise and 1 MW = 6820 gpm for 20pF = 341 gpm.

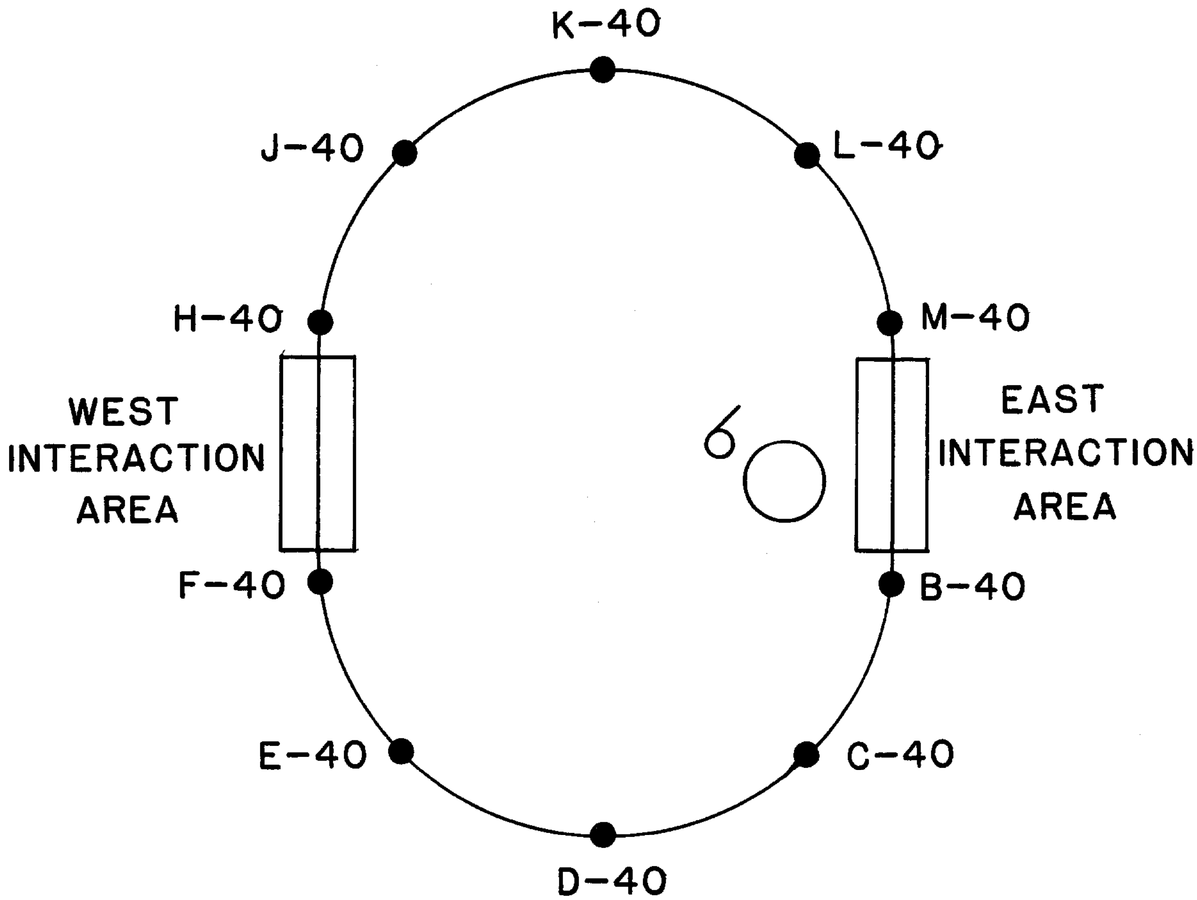
Footnotes:

1. Thermal Pollution of Ground Water by Artificial Recharge, Robert T. Sasman, Water & Sewage Works, Vol. 119 December 1972 pp52-55.

2. Cooling Pond Many Answer Your Water Cooling Problem, J.W. Langhaar,; Chemical Engineering, August, 1953, pp 194-199.

3. Fifteen-Year Climatological Summary, ANL Report, 7084, Harry Moses & Mary a Bogner. September 1967.

4. Scaling Tendency Determined Using Ryzmar Method: A New Index for Determining Amount of Calcium Carbonate Scale Formed By a Water, John W. Ryznar; Journal of American Water Works Association, Vol. 39, November, 1947, pg 1090.

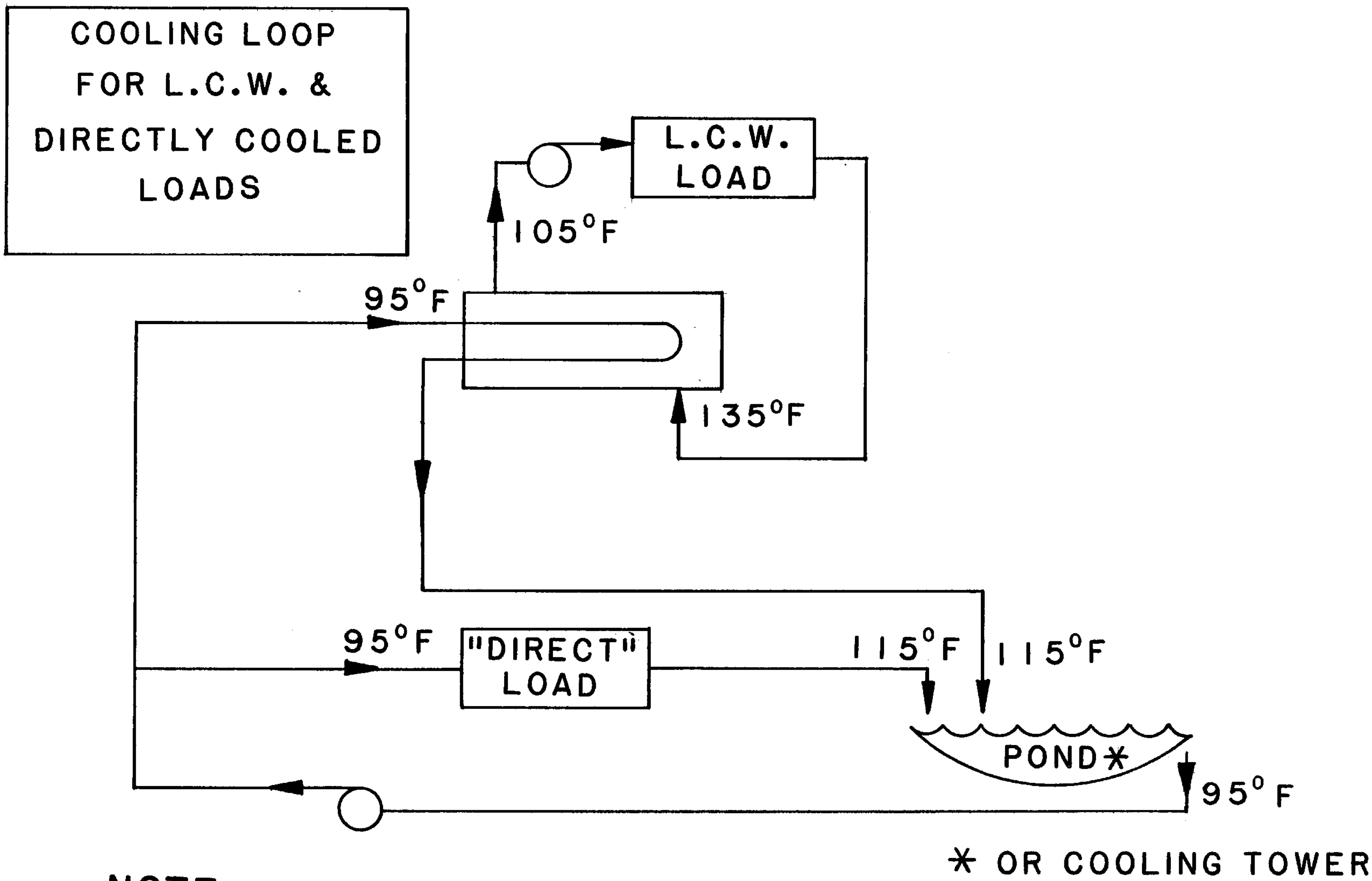


MAJOR HEAT REJECTION AREAS

2 INTERACTION AREAS

10 MAJOR ACCESS AREAS

FIGURE 1



NOTE:

TEMPERATURES ARE FOR "WORST CASE" (99%) CONDITIONS

FIGURE 2

TABLE #1 HEAT REJECTION AT EACH MAJOR ACCESS AREA

LOAD		Type of Water Req'd	Flow Rate Thru Load, GPM	HEAT REJECTION RATE VIA COOLING WATER, MW	MAX INLET TEMP TO LOAD, ^{O}F	TEMP RISE THRU LOAD, ^{O}F	COOLING POND(or tower) Flow Rate, GPM @ $20^{O}F$ Rise	"Ground Water Recharge" Flowrate, GPM @ $40^{O}F$ Rise	Make-Up Water Req'd (@ 2 cycles of concentration) gpm: Towers	(1) Ponds	Ground Water(2) Recharge	Dry Towers Water to Air
Power Supplies & Elec (733 MW)		LCW	250	0.733	105	30	375	188	9.6	8.8	0	0
Refrig-erator Cooldown Mode (4MW)		POND	1350	4	95	20	1350	675	52.5	48	0	0
Normal Operating Mode (2MW)		POND	675	2	95	20	675	338	26.2	24	0	0
HVAC (300KW)		POND	130	0.375	95	20	130	65	4.9	4.5	0	0
TOTALS	PEAK			5.1			1855	928	67	61.3	0	0
	NORMAL			3.1			1180	591	40.7	37.7	0	0

(1) Make-Up water requirements for ponds is annual average. Rates vary from 6.06 to 18.25 gpm/MW see Table 4

(2) Ground water recharge system is a "Once Thru" system hence the cycles of concentration equals zero.

(3) Dry Towers require annual "winterizing" with 50% ethyelene glycol/water mixture.

TABLE #2 EAST AREA

LOAD	TYPE oF WATER REQ'D	PEAK/NORMAL	FLOW RATE THUR LOAD, MW	Heat Rejection Rate VIA COOLING WATER, MW	MAX INLET TEMP TO LOAD, ^oF	TEMP RISE THRU LOAD, ^oF	COOLING POND(or tower) FLOW RATE, GPM @ 20^oF RISE	"GROUND WATER RECHARGE" FLOWRATE, GPM @ 40^oF RISE	Make-Up Water Req'd (@ 2 cycles of concentration) gpm: Towers	(1) Ponds	GROUND WATER(2) RECHARGE	"DRY"TOWERS WATER TO AIR
NiASP 3 I.R. 2 Refrig. Misc.	POND	Peak	10250	30	95	20	10,250	5125	394	360	0	0
		Normal	5800	17	95	20	5800	2900	223	204	0	0
Injection Power Supplies R.F. Misc. P.S.	LCW	Peak	4640	13.6	105	30	6960	3480	178	163	0	0
		Normal	3750	11	105	30	5625	2813	144	132	0	0
TOTALS	Peak			43.6			17,210	8605	572	523	0	0
	Normal			28			11,425	5713	367	336	0	0

(1) Make-Up water requirements for ponds is annual average. Rates vary from 6.06 to 18.25 gpm/MW see Table 4.

(2) Ground water recharge system is a "Once Thru" system hence the cycles of concentration equals zero.

(3) Peak Loads are estimated @ 80% of installed electrical power.

TABLE #3 HEAT REJECTION
AT WEST AURORA

LOAD	TYPE oF WATER REQ'D	PEAK/NORMAL	FLOW RATE THRU LOAD, GPM	Heat Rejection Rate VIA COOLING WATER, MW	MAX INLET TEMP TO LOAD, °F	TEMP RISE THRU LOAD, °F	COOLING POND (or tower) FLOW RATE, GPM @ 20°F RISE	"GROUND WATER RECHARGE" FLOWRATE, GPM @ 40°F RISE	Make-Up Water Req'd (@ 2 cycles of concentration) gpm: Towers	PONDS	Ground Water(2) Recharge	"DRY" Tower Water-to-Air
NiASP 3 I.R. 2 Refrig. Misc.	POND	Peak	11050	32.4	95	20	11050	5525	425	389	0	0
		Normal	7502	22	95	20	7502	3751	289	264	0	0
Power Supplies	LCW	Peak	2182	6.4	95	30	3275	1638	84	77	0	0
		Normal	955	2.8	95	30	1433	717	38	34	0	0
TOTALS	PEAK		13232	38.8			14325	7163	509	466	0	0
	NORMAL		8457	24.8			8935	4468	327	298	0	0

(1) Make-Up water requiements for ponds is annual average. Rates vary from 6.06 to 18.25 gpm/MW see Table 4.

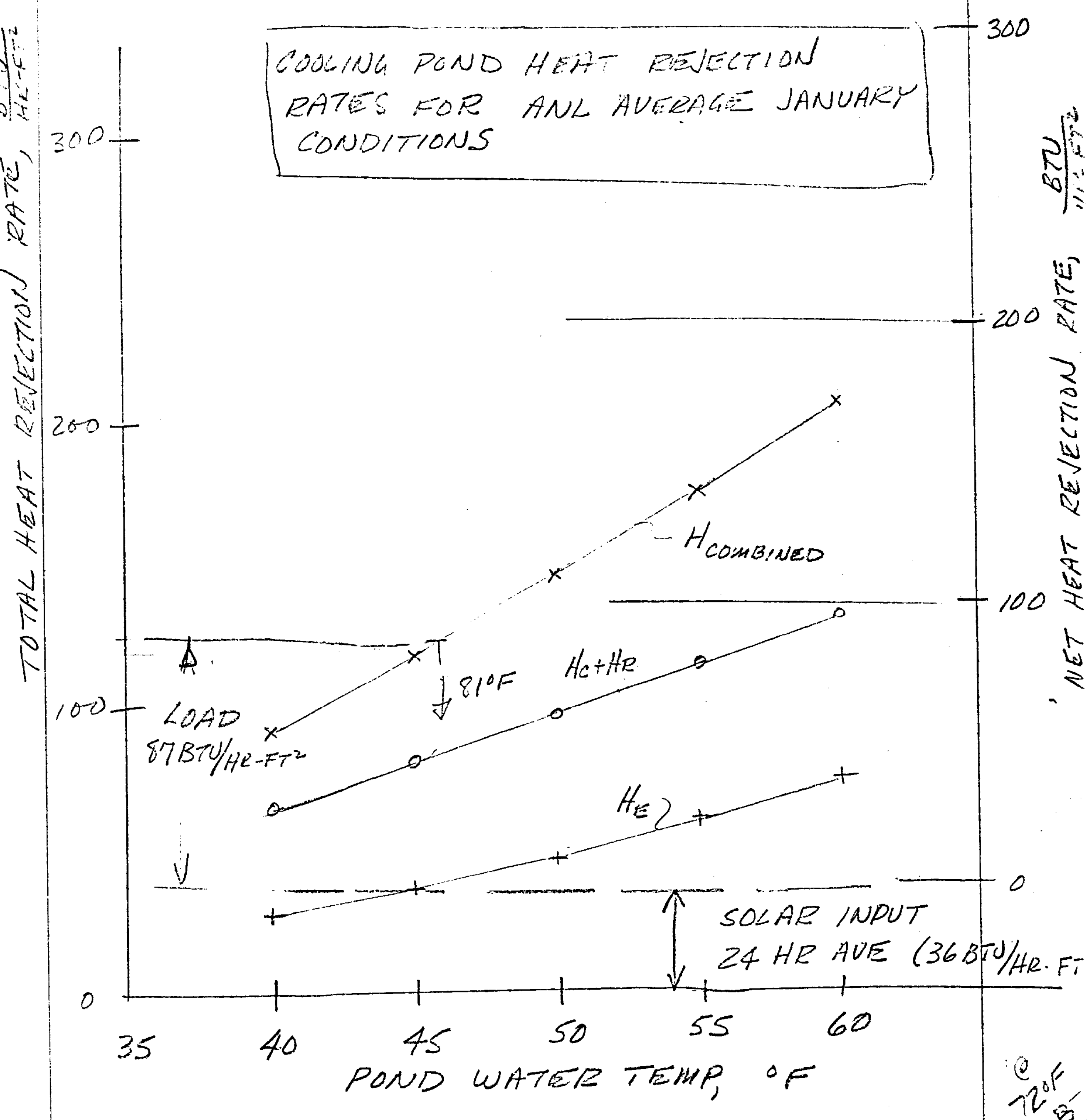
(2) Ground water recharge system is a "Once Thru" system hence the cycles of concentration equals zero.

(3) Peak Loads are estimated @ 80% of installed electrical power.

ESTIMATED WATER CONSUMPTION PER MEGAWATT

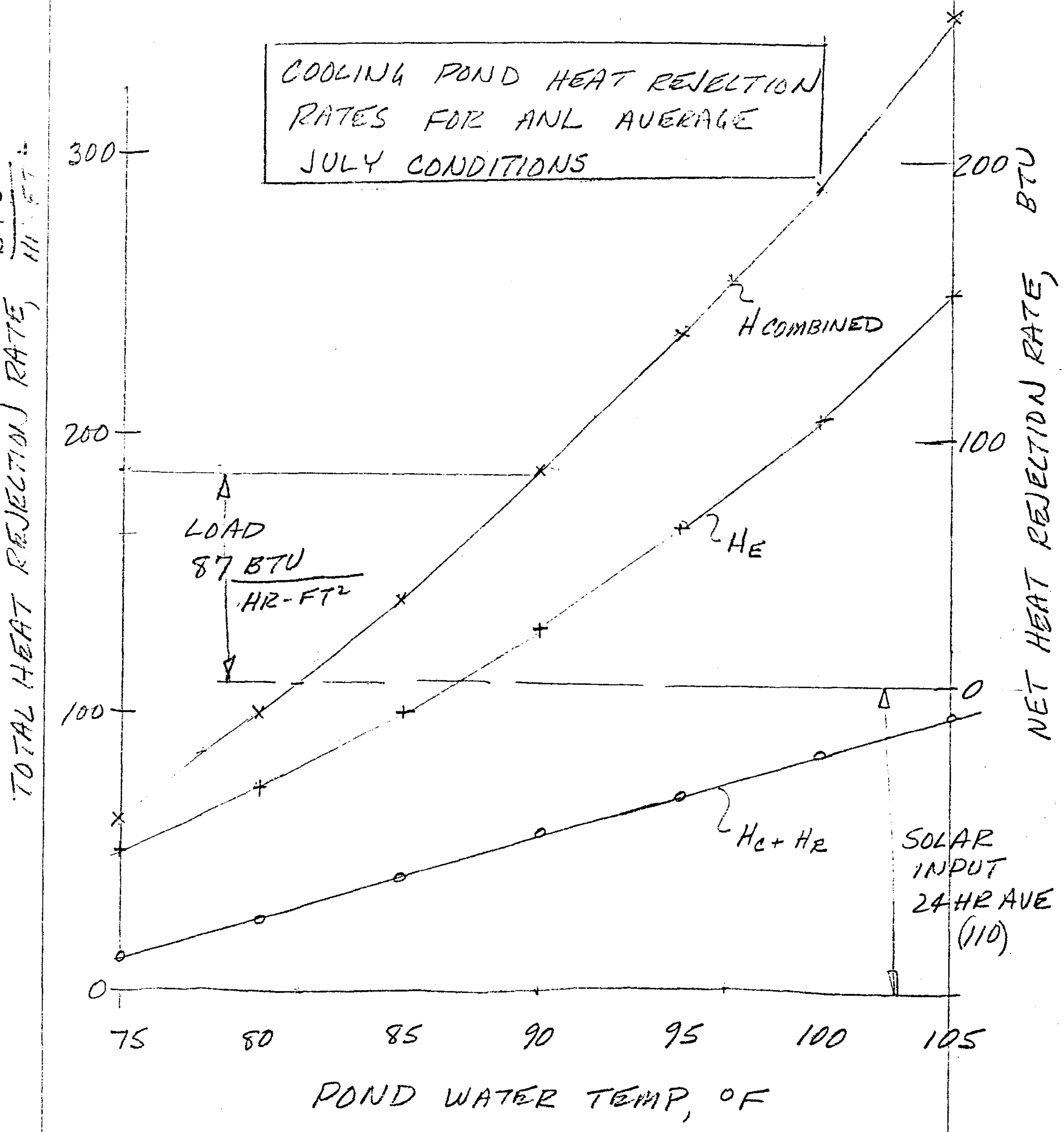
	TOWERS			PONDS		
	Evap rate	Makeup	Bleedoff + Windage	Evap rate	Makeup	Bleedoff
Winter	6.56	13.12	13.12	3.03	6.06	3.03
Summer	6.56	13.12	13.12	9.25	18.25	9.25
Annual Average	6.56	13.12	13.12	6.00	12.0	6.0

TABLE 4 ESTIMATED WATER CONSUMPTION PER MEGAWATT



AVERAGE DRY BULB	21°F
AVERAGE DEW POINT	17°F (.088843 in Hg)
AVERAGE WIND VEL	13.13 MPH @ 150 FT
24 HR AVE. SOLAR INPUT	36 BTU/HR-FT²

JSOM
19 Sept '8



AVERAGE DRY BULB	71°F
AVERAGE DEW POINT	60.5°F (.53103 in Hg)
AVERAGE WIND VEL	9.6 MPH (@150 FT)
24 HR AVE SOLAR INPUT	110 BTU/HR-FT²

J. [illegible]
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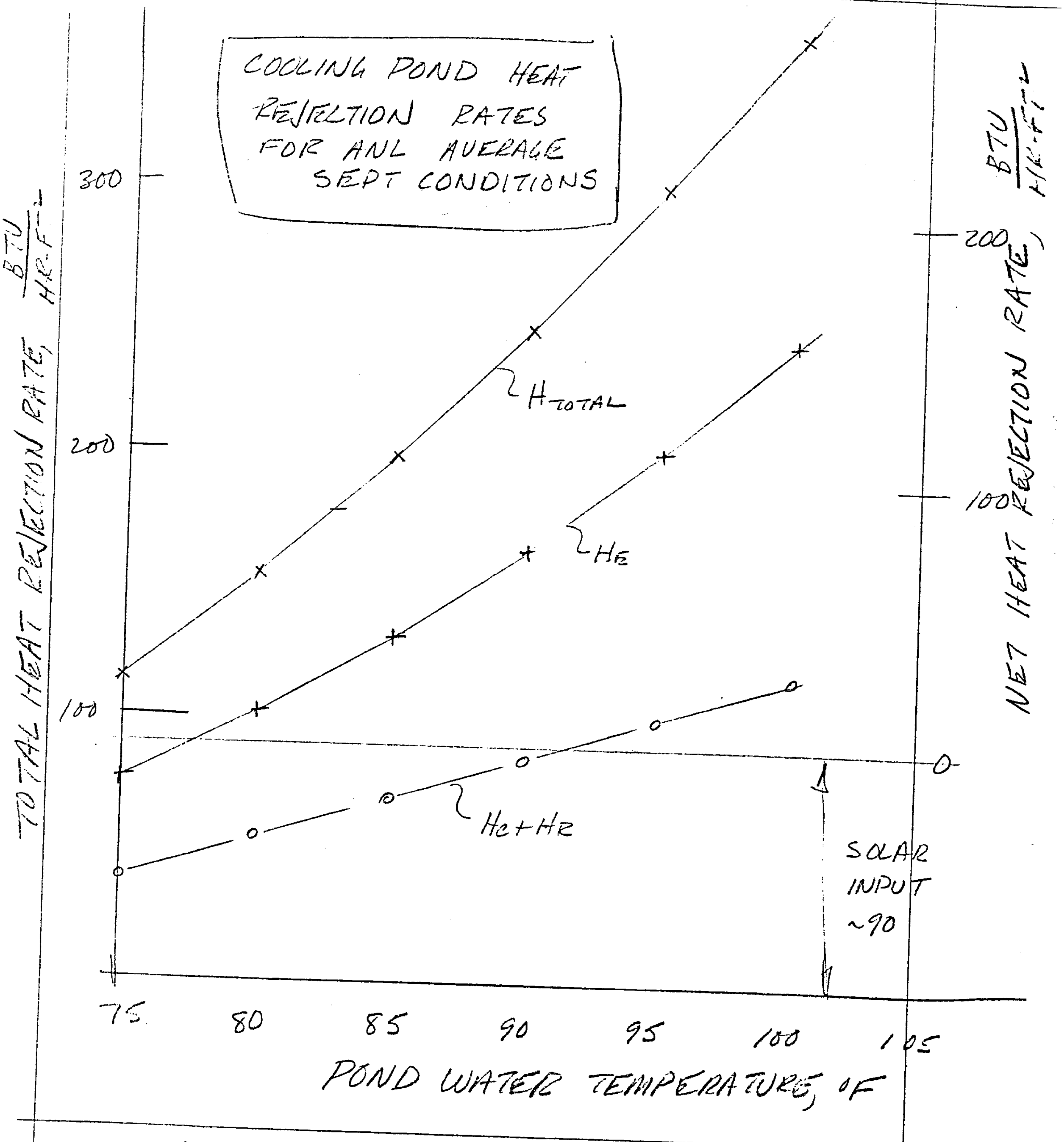


AVERAGE DRY BULB	63°F
AVERAGE DEW POINT	52°F (.39028 in Hg)
AVERAGE WIND VEL	13.13 MPH (@150 FT)
SOLAR INPUT 24 HR AVE	90 BTU/HR-FT²

.3/2/87
CASEY'S POND

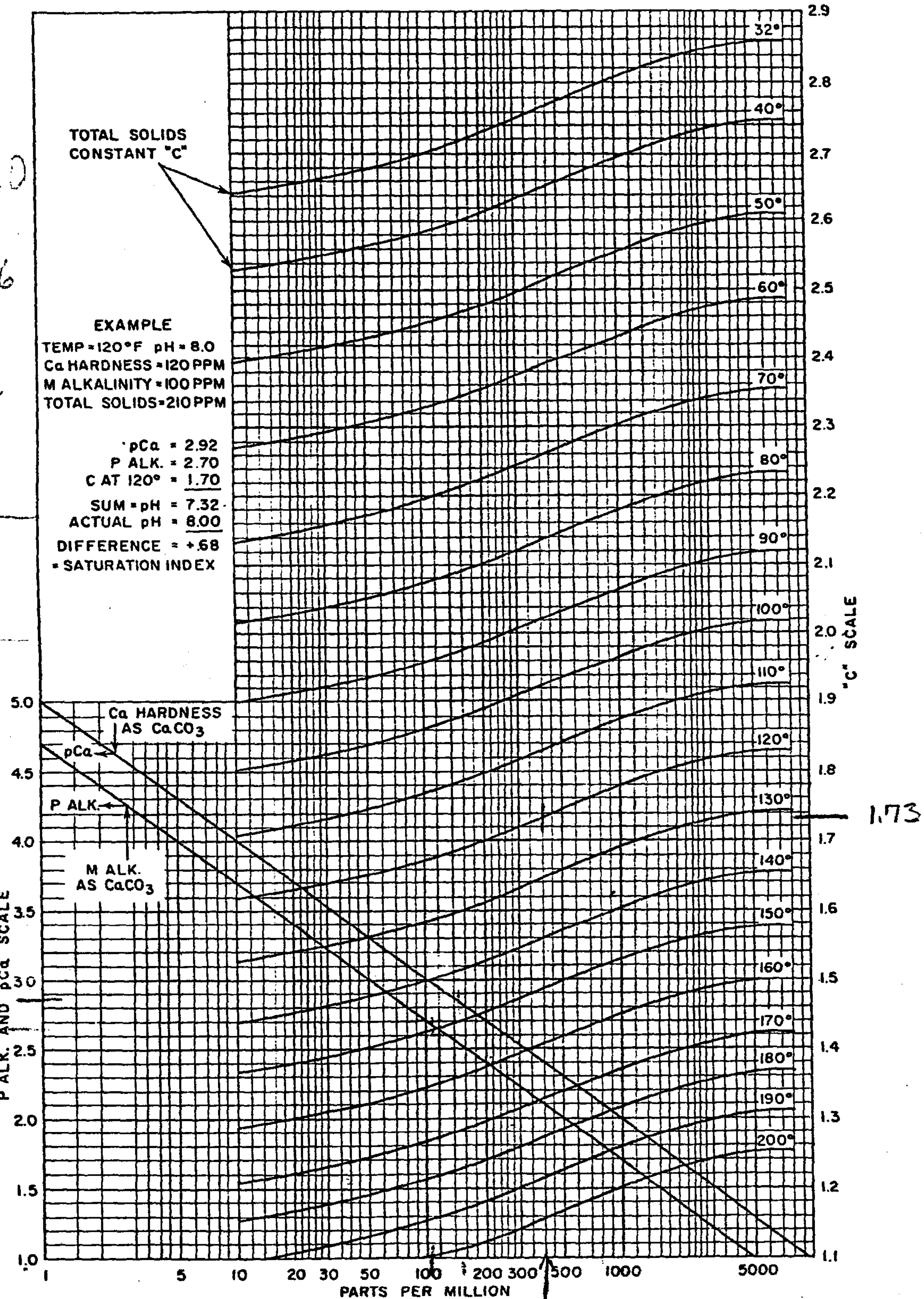
CHART 5—LANGELIER SATURATION INDEX

pH = 7.9
TDS = 400
Total Hardness] 250
Ca Hardness] 156
alk mo] 112

pCa 2.95
pAlk 2.65
C_{120} 1.73
7.33

7.9 - 7.33 =
Is = +.57

2.95



STAB INDEX
pHs - pHact
2(7.33 - 7.9)
= 6.76 little scale or corrosion

From Water Conditioning For Industry, by Sheppard T. Powell. McGraw-Hill Book Co. Inc., 1954. Used by permission.

Water & Sewage Works, Vol. 119, No. 12.
December, 1972, p52-55

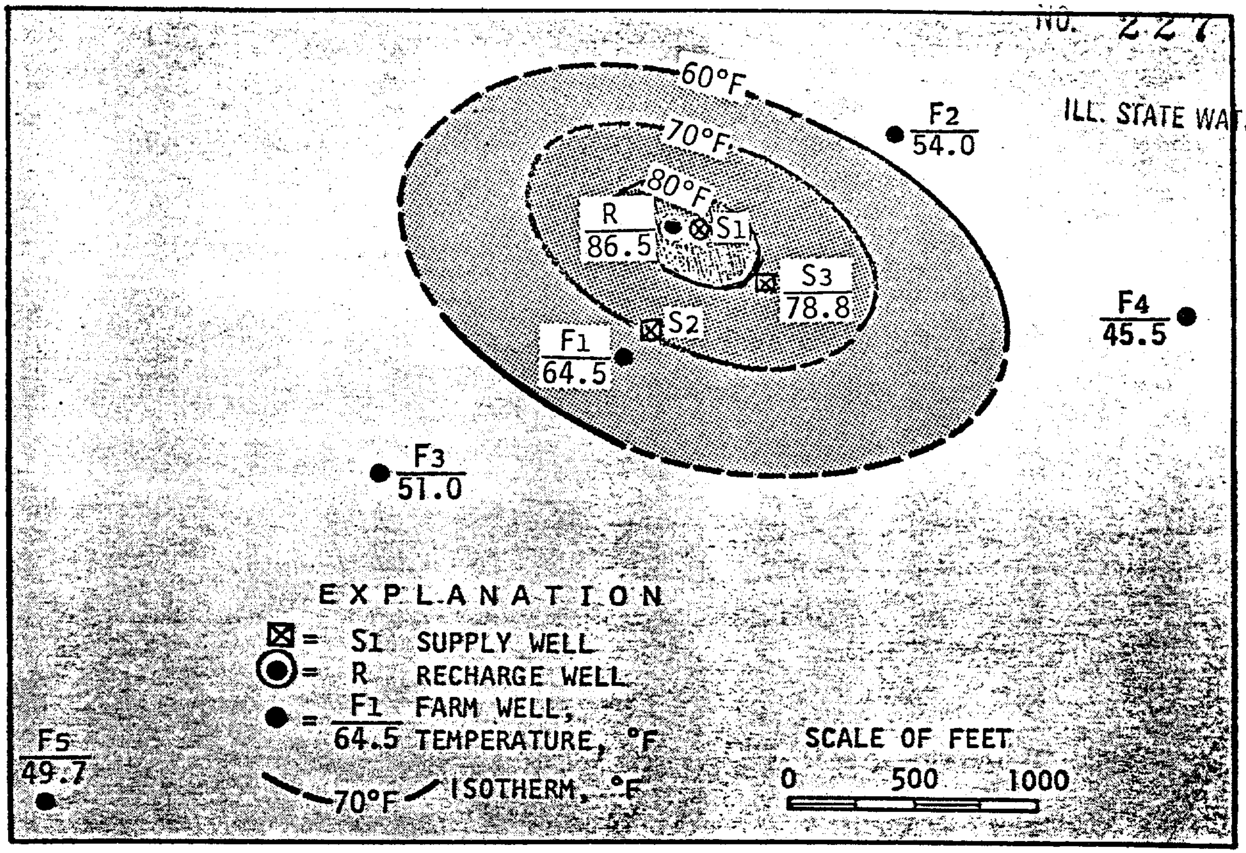


Figure 1. Well locations and ground water temperature in area of recharge operation.

Thermal pollution of ground water by artificial recharge

By Robert T. Sasman*

Projected large increases in municipal and industrial ground water pumpage in northeastern Illinois indicate ground water demands will exceed ground water availability in some areas in 1990. The total ground water pumpage has increased steadily at an accelerating rate since the first high capacity well was drilled in 1864. Pumpage has increased at an average rate of 8.3 million gallons per day (mgd) every year since 1960 and was 260 mgd of 1970 (Table 1). Projections of ground water pumpage to the year 2020 made by Schicht and Moench, indicate a demand of 314 mgd by 1980 and 923 mgd by 2020.[1] In 1970 more than 53 percent of the total pumpage was obtained from wells finished in deep sandstone formations. This is expected to increase to about 60 percent of the total pumpage by 2020, or 556 mgd.

But as pumpage from deep sandstone wells has increased, water levels in these wells have drastically declined, approaching 800 ft in the areas of heaviest pumpage. Long term water level declines have averaged 7-8 ft/yr. The average decline for the period 1958-1966 was nearly 14 ft/yr. Schicht and Moench[1] predict that the water level will decline an additional 500 feet in some areas within the next 20 years.

There are several alternative programs that can be considered in attempts to balance supply and demand. These include artificial ground water recharge, industrial water recirculation, reuse of treated sewage plant effluent, importation of either ground water or surface water from sources outside the metropolitan area, restrictions on use and increased diversion from Lake Michigan.

In spite of declining water levels and associated deeper pump settings and larger pumps, numerous municipalities and industries continue to develop additional water supplies from the deep sandstone aquifers. One of the major reasons for this is that these aquifers can still provide uniformly moderate to high yields to wells throughout the region. Arti-

*Hydrologist, Illinois State Water Survey, Warrenville, Illinois.

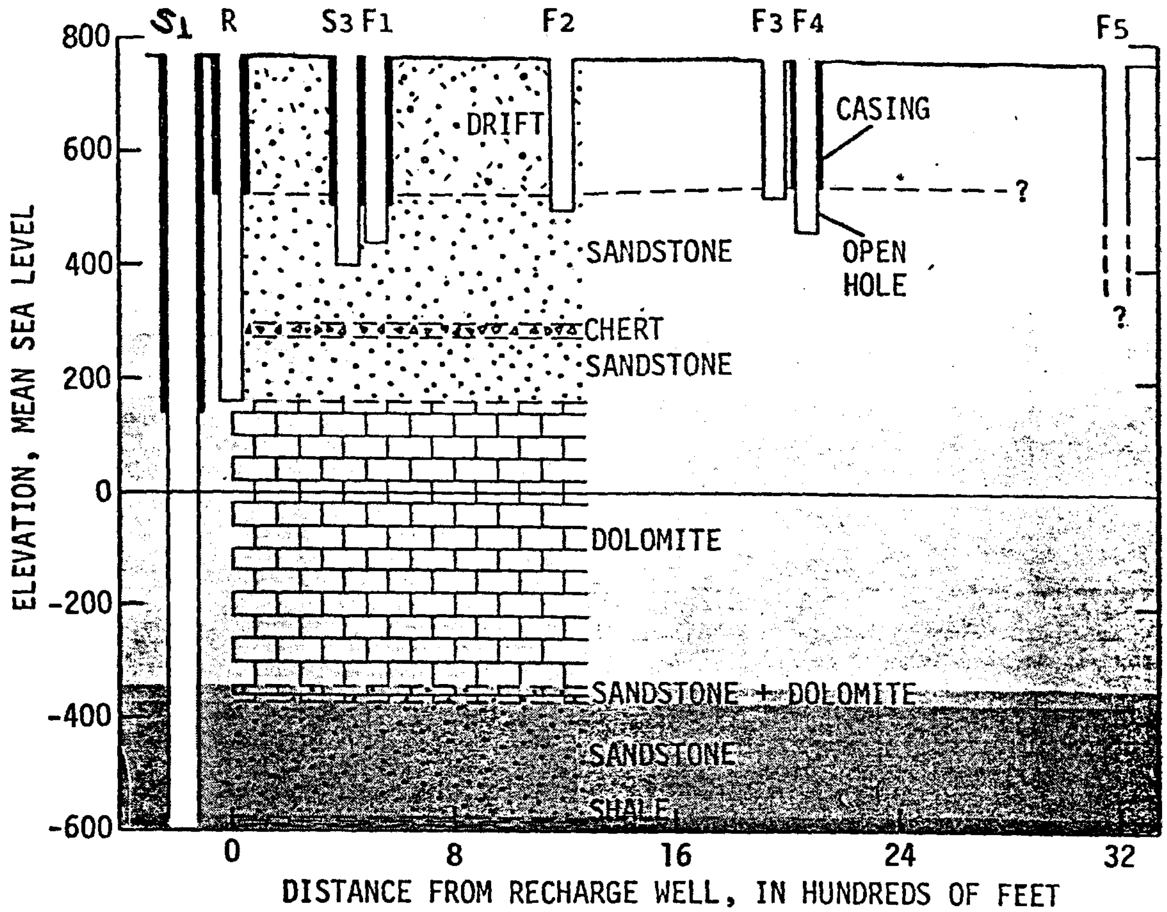


Figure 2. Generalized geologic profile in area of recharge operation.

ficial recharge of the deep sandstones is one method by which the high productivity can be maintained. The great decrease in the water levels will permit recharge with gravity injection.

Recharge Water

One source of recharge water is water used for cooling purposes in various industrial processes. According to McDonald and Sasman, there are five industries in northeastern Illinois recharging cooling water at rates of 25,000-395,000 gpd.[3] This water flows through closed circulation systems and its mineral character is not changed. It does undergo an increase in temperature, however. Since water quality requirements of many industrial processes are particularly vulnerable to increases in temperature, recharging high temperature cooling water may ultimately increase well water temperatures and seriously affect the industrial operations. This article describes the effect on well water temperatures of one industry recharging high temperature cooling water effluent.

The water for this industry is, primarily, obtained from a 1348-ft deep well (well No. 1 in this article) and a 1353-ft deep well (well No. 2 in this article) both finished in the Ironton-Galesville Sandstone. These wells are cased and cemented to depths of 632 and 639 ft, respectively. They are approximately 450 ft apart. The water is used primarily for cooling air conditioning condensers and, intermittently, for cooling emergency engine alternators. Water circulates through a closed piping system and is returned to the ground through a recharge well 608 ft deep, cased to a depth of 244 ft. The recharge well is 50 ft from supply well No. 1 and approximately 435 ft from supply well No. 2. Recharge occurred at a continuous rate of 500-600 gpm during the first five years of plant operation. During the past four years, the recharge rate has been about 200-300 gpm. A third supply well at the site has a depth of 373 ft

Table 1. Groundwater pumpage trends and demand projections*

Date	Pumpage (mgd)
1900	31
1940	85
1960	177
1970	260
1980	314 (projected)
2020	923 (projected)

*Includes Cook, DuPage, Kane, Lake, McHenry, and Will Counties

Table 2. Generalized stratigraphy and water-yielding properties of rocks in northeastern Illinois.

Geologic Units	Thickness (ft)	Water Yielding Properties
Glacial drift	0-400+	Yields of wells variable, some well yields greater than 1000 gpm
Silurian dolomite	0-400+	Yields of wells variable, some well yields greater than 1000 gpm
Maquoketa shale	0-250	Generally not water yielding, acts as barrier between shallow and deep aquifers
Galena-Platteville dolomite*	150-350	Water yielding where not capped by shales
Glenwood-St. Peter sandstone*	75-650	Estimated transmissivity 15 percent that of Cambrian-Ordovician aquifer
New Richmond, Oneota, Potosi, and Franconia Formations*	45-750	Estimated transmissivity 35 percent that of Cambrian-Ordovician aquifer
Ironton-Galesville sandstone*	103-275	Estimated transmissivity 50 percent that of Cambrian-Ordovician aquifer
Eau Claire shale	235-450	Generally not water yielding, acts as barrier between Ironton-Galesville and Mt. Simon
Eau Claire and Mt. Simon sandstones	2000±	Moderate amounts of water, permeability between that of Glenwood-St. Peter and Ironton-Galesville, water quality problem with depth

*Collectively referred to as Cambrian-Ordovician aquifer

Table 3. Groundwater temperature at measured distances from recharge well.

Well No.	Depth (ft)	Distance from Recharge Well (ft)	Water Temp. (°F)
Supply Well 1	1348	50	57.9
Supply Well 3	373	450	78.8
Farm Well 1	330	525	64.5
Farm Well 2	275	1000	54.0
Farm Well 3	241	2000	51.0
Farm Well 4	302	2000	45.5
Farm Well 5	?	3200	49.7

and a capacity of about 200 gpm. During recent years it has been used in the winter instead of wells 1 and 2 when a smaller capacity is required.

The structure and general characteristics of the rocks beneath northeastern Illinois are shown in Table 2. Available records indicate that the glacial drift is 225-250 ft thick in the general vicinity of the recharge installation and overlies the St. Peter Sandstone, the top bedrock formation. This formation is 250 ft thick and is composed primarily of fine to coarse grained sandstone. Underlying the St. Peter Sandstone are nearly 100 feet of New Richmond Sandstone. This is followed by more than 500 ft of dolomite of the Oneota, Potosi and Franconia Formations. The Ironton-Galesville Sandstone, below the Franconia Formation, is 207 feet thick and penetrated by the two deep supply wells.

Upon completion, the recharge well had a specific capacity of 11.8 gpm/ft of drawdown. Initial injection tests were conducted with supply well No. 1 pumping 1620 gpm.

Warmer Water

The temperature of the water entering the recharge well varies from about 85-110 °F, depending in part on the volume of water used for cooling, the supply well being used and the season of the year. No significant mechanical problems have occurred with the recharge operation. However, in April, 1970, a farmer on property adjoining the installation noticed that water from his well was warmer than normal. A subsequent investigation revealed a marked increase in ground water temperature for a distance of at least 525 ft from the recharge well.

Water temperatures were measured in the recharge well, the supply well in operation (No. 1), the shallow supply well and five farm wells in the area during a 4-hr period on one day (Table 3). Water was entering the recharge well at a temperature of 86.5 °F and water from supply well No. 1 was 57.9 °F. Previously recorded temperatures for water from the two deep supply wells had been 57.5 °F and 60 °F. The recharge rate during the investigation was 320 gpm.

Supply well No. 3, the shallow supply well, had not been in operation for some time prior to the investigation. When the pump was turned on, the water temperature rose rapidly from 50 °F to 78.8 °F, and then remained constant. One farm well was in operation at the time of the investigation. The temperature of the water at other farm wells varied only slightly during pumping periods of 15-30 min. The farm wells are usually not pumped continuously for extended periods.

The five farm wells studied are located less than a mile from the recharge installation (Fig. 1). The wells range in depth from 241-330 ft and penetrate the St. Peter Sandstone (Fig. 2). The recharge well is open to both the St. Peter and New Richmond Sandstones. The deep supply wells are cased into the Oneota Dolomite below the New Richmond Sandstone.

The temperature of water from wells finished in glacial drift and upper bedrock formations varies somewhat with the time of year, the depth of the well, the depth and thickness of the water bearing formation, and the length of pumping time before the temperature is measured. Records are available for water temperatures from seven wells in the general area though these wells are several miles from the specific location (Table 4). The depths of these wells range from 183-500 ft and the recorded temperatures range from 52 °F to 57.6 °F. The average temperature of the seven wells listed in Table 4 is 55.1 °F. Although this is a few degrees warmer than water from three of the farm wells, it is considerably colder than the two farm wells closest to the recharge injection wells.

A temperature gradient curve (Fig. 3) shows that high temperature recharge water has had a significant effect on the groundwater temperature in the general vicinity, for a distance of at least 500 ft from the recharge well, and perhaps as far as 1000 ft.

Another development has caused additional concern regarding the continued operation of the recharge system at the installation. After an idle period of about three months, the temperature of water from supply well No. 1 (nearest the recharge well) was 88 °F. Within a few hours of operation, the temperature lowered to 60 °F, which is in the normal range for water from this well. Recent recharge water temperatures have ranged from 90 °F to 110 °F. Although the plant has been in operation for nine years and the supply well previously had been idle for periods up to several weeks, this was the first time a high temperature water from the supply well had been detected. In looking for a reason for the high temperature, a check valve in the system was discovered to be defective. With supply well No. 1 not operating, part of the normal flow of water was reversed and heated water was entering the deep sandstone formation through the idle supply well. Repair of the check valve corrected this condition.

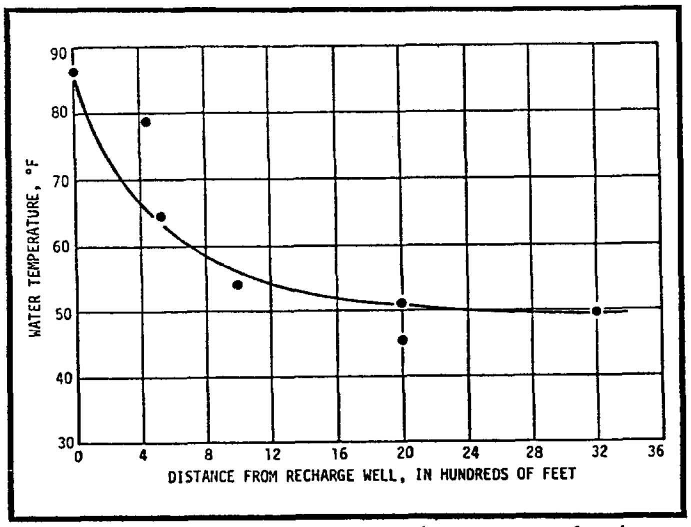


Figure 3. Ground water temperature gradient in area of recharge operation.

Table 4. Selected well water temperatures in general region of recharge operation.

Well Depth (ft)	Water Temp. (° F)	Month Measured
183	54.0	Sept.
230	54.5	May
298	52.0	Oct.
402	57.5	Apr.
418	55.7	Apr.
451	54.9	May
500	57.6	Feb.
Average	55.1	
Median	54.9	

Conclusions

No undesirable effects have been reported at four of the five groundwater recharge installations in northeastern Illinois, other than some associated with the actual mechanics of the operation. Recharge rates at these four installations reportedly range from approximately 25,000-395,000 gpd. All of these facilities have been in operation nine years or more.

Under certain conditions of geologic formation permeability, recharge rates and water temperaure, it appears highly probable that the normal ground water temperature will be raised significantly for some distance from the recharge installation. As a result of this study it seems desirable that additional consideration should be given to this problem in future operations of this type. Monitoring the recharge injection rate, water levels, temperature and quality of the injection water and of the ground water at one or more observation sites at different distances from the injection site would be beneficial in attempts to determine long-range effects on ground water aquifers. ■

References

1. Schicht, R. J. & Moench, A. Projected Groundwater Deficiencies in Northeastern Illinois, 1980-2020. Illinois State Water Survey Circular 101 (1971).
2. McDonald, C. K. & Sasman, R. T. Artificial Groundwater Recharge in Northeastern Illinois. Groundwater (April, 1967).
3. Sasman, R. T. Industrial Water Recirculation in Northeastern Illinois. American Water Works Association (May, 1970).
4. Csallany, S. C., Roberts, W. J. & Towery, N. G. Illinois P-260 State Water Resources Planning Project Progress Report. Technical Appendix to the Report on Priority and Planning Elements for Developing Illinois Water Resources, Illinois Department of Business and Economic Development (1969).